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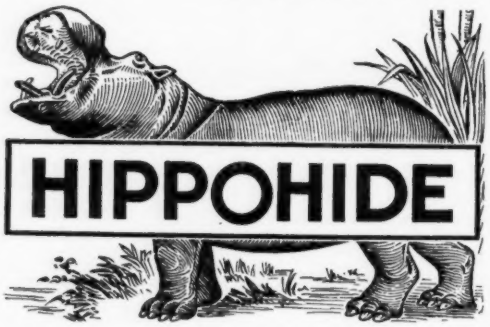

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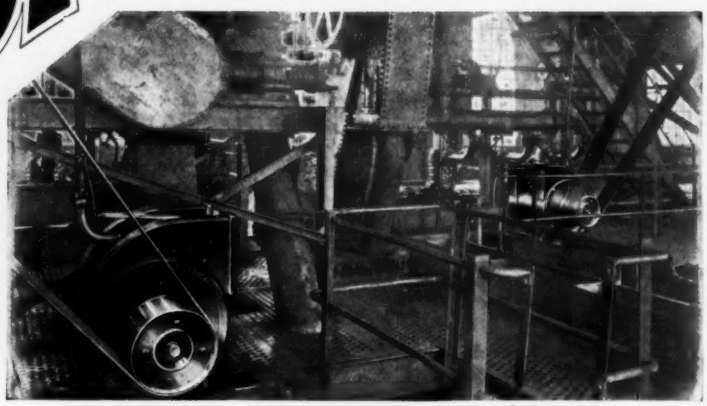

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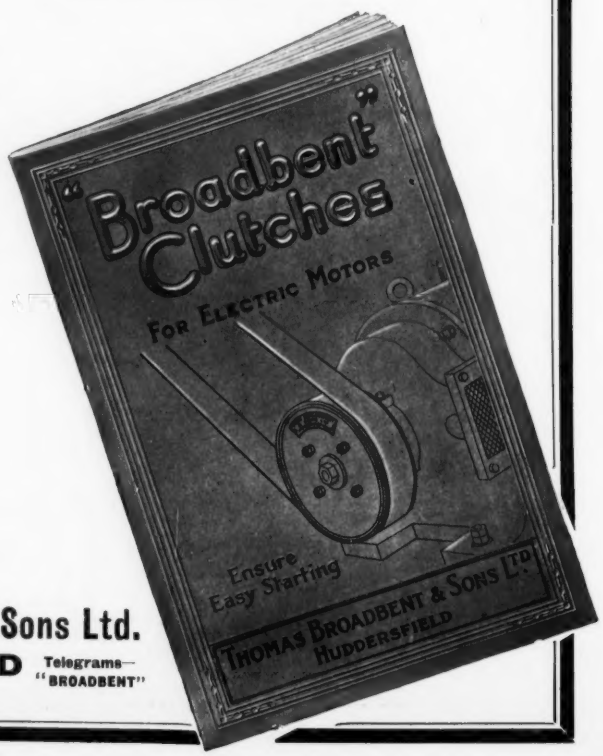

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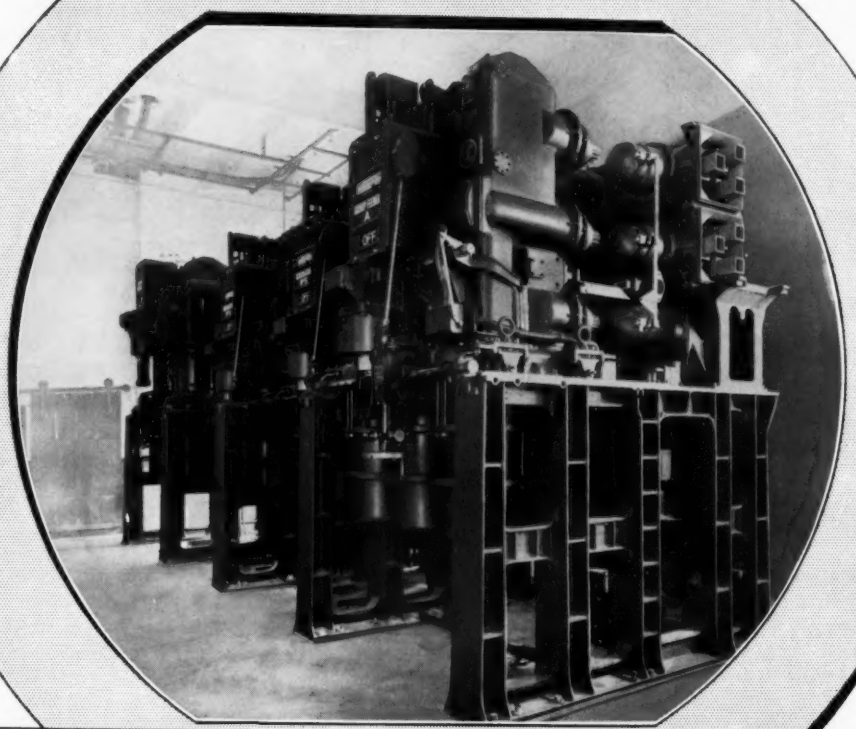

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The celluloid " take-off " fingers are mounted on eccentric collars, which are free to move along the supporting rod. Both rod and collars are heavily chromium plated.

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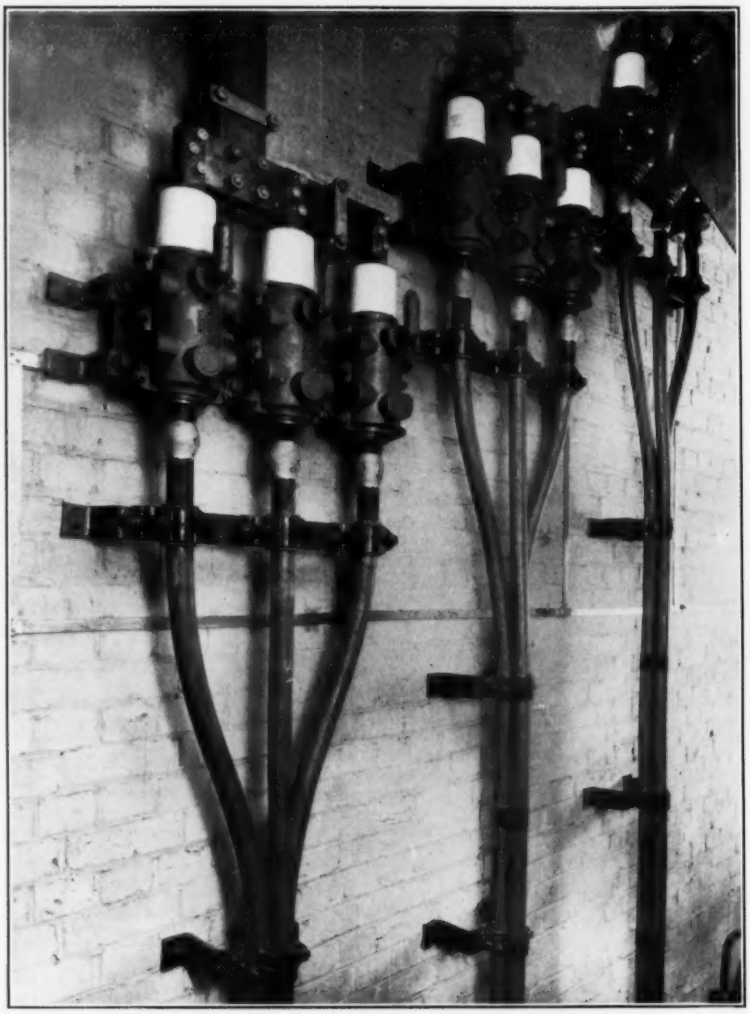

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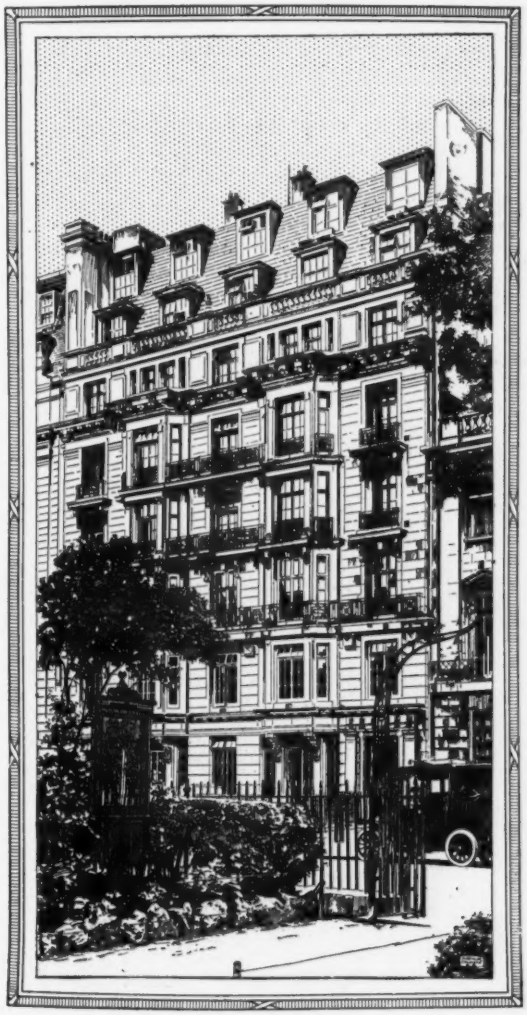

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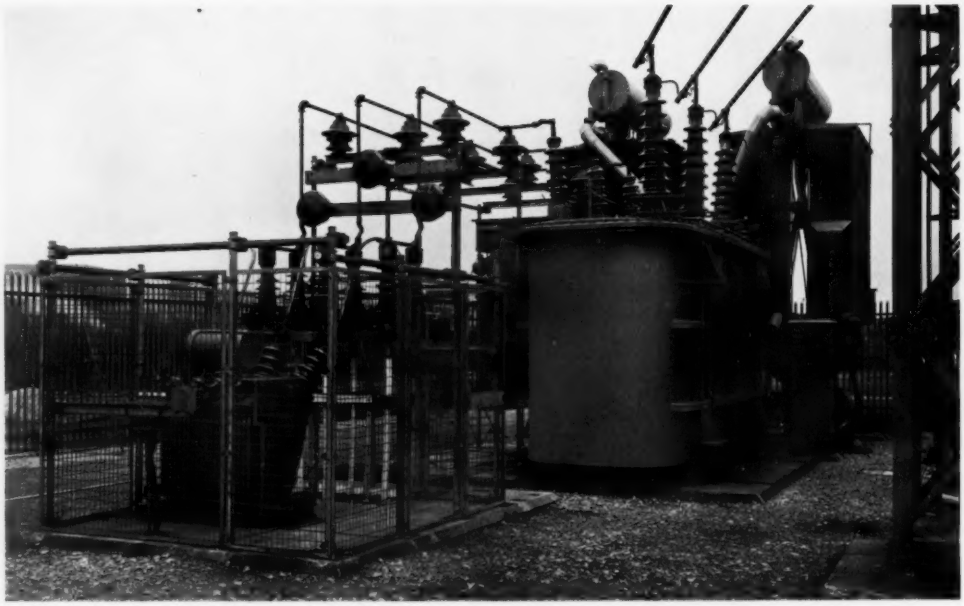

Large Responsibilities.—*57 "English Electric" Motors, totalling 2,000 H.P. operated the two erection cranes on the Sydney Harbour Bridge. The lower picture shows a 45,000 kVA., 132,000-volt Transformer with on-load tap-changing gear in service on the "Grid."*

The English Electric Journal

Vol. VI. No. 1 APRIL, 1932 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

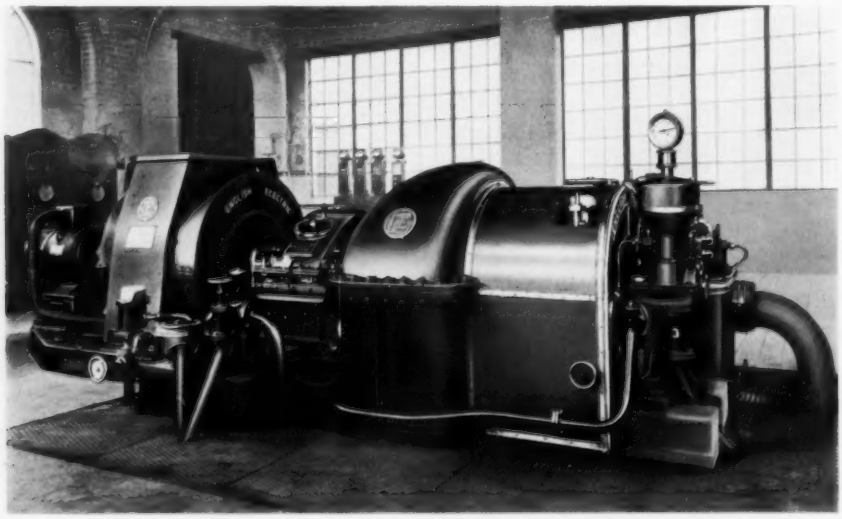
The subjects of our frontispiece illustrations will interest our readers, we believe, because in their different branches of engineering they are fitting examples of the high standard of achievement maintained by British craftsmanship at the present day. Both structures represent contributions of an important kind to the necessities of modern life, the one to facility of communication, and the other to rendering generally available a service of electric power. They represent, too, a concentration of effort and of purpose which laid a great responsibility on all who contributed to their making, for they are vital parts of essential services to a large number of people. Traditions of responsibility and service run throughout the organisation of the English Electric Company, and the large-scale applications of electricity which it has completed in the past, many of a pioneer character, are a reliable indication of its capabilities to carry through to a satisfactory conclusion any undertaking upon which it may embark.

With the first public transmission from the Northern Regional Broadcasting

Station early in May, another group of the Company's high-tension direct-current machinery is put into routine service. The earlier regional stations at Brookman's Park and Sleathwaite are equipped with similar 12,000-volt generators and switch-gear, and they are to be installed also in the Western Station that is now being erected.

In our issue of November, 1930, we pointed out that the whole of the large modern water turbine plant in Scotland had been manufactured by the Company, with an aggregate capacity of 114,000 horse-power. With the placing of an important order by the Galloway Water Power Company, that record continues, and the figure of total output is extended to nearly 200,000 horse-power. The contract comprises eight water turbines and generators together with a considerable amount of switchgear and transformers.

An article in this issue describes the current practice of the Company in the construction of steam-turbine generating plant for small or medium outputs. These modern designs of plant are frequently selected by industrial undertakings in this country and abroad, especially for industries in which problems of steam economy, as distinct from power production, play an important part. Low-pressure steam can be obtained most economically by the use of a pass-out turbine, or exhaust steam from other plant can be made to yield further power in a turbine of the mixed-pressure type. The details of the surface-type of plant have been worked out with special regard to the reduction of installation and supervision costs.



750 kW., Mixed-pressure Geared Turbo-alternator Set in a Staffordshire Colliery. Other examples of modern steam turbine plants of small and medium output are illustrated in an article in this number.

Portsmouth's New Switching Installation.

Fig. 1.—The New Switch House in the foreground adjoins the Turbine Room.

Since the supply of electricity became a municipal responsibility thirty years ago, the history of the Portsmouth Electricity Department has been a record of continuous progress both technically and in the popularity of the service. The total area supplied is 182 square miles, and, in addition, undertakings to whom bulk supplies are given serve a further 178 square miles. As the result of a favourable scale of charges, coupled with reliable service and enterprising sales methods, the output has increased to a figure that is eight times that recorded twelve years ago, exclusive of the energy furnished to the Tramways and to bulk purchasers.

The capacity of the power station having increased with corresponding rapidity, the Engineer and Manager, Mr. B. Handley, M.I.E.E., recognised that the main switchgear had to be brought into proper relation with the generating plant if the same standard of reliable service was to be maintained, and he accordingly planned the switching installation that was formally inaugurated on April 20th, by the Lady Mayoress, in the presence of a large number of visiting engineers and local residents. The course of future development was fully considered in preparing the proposals, and the installation as a whole and the size of the individual units have been made adequate for the conditions that will arise when the system is linked with the Grid.

A new self-contained switch house has been erected and, owing to the limited space available on the site, this has taken the form of a three-storey building, having connection with the turbine room only through a door on each floor accessible from an iron staircase. The main switching apparatus is distributed on the two lower floors, while the top floor is occupied only by the control boards, by means of which the attendant has full supervision and control over

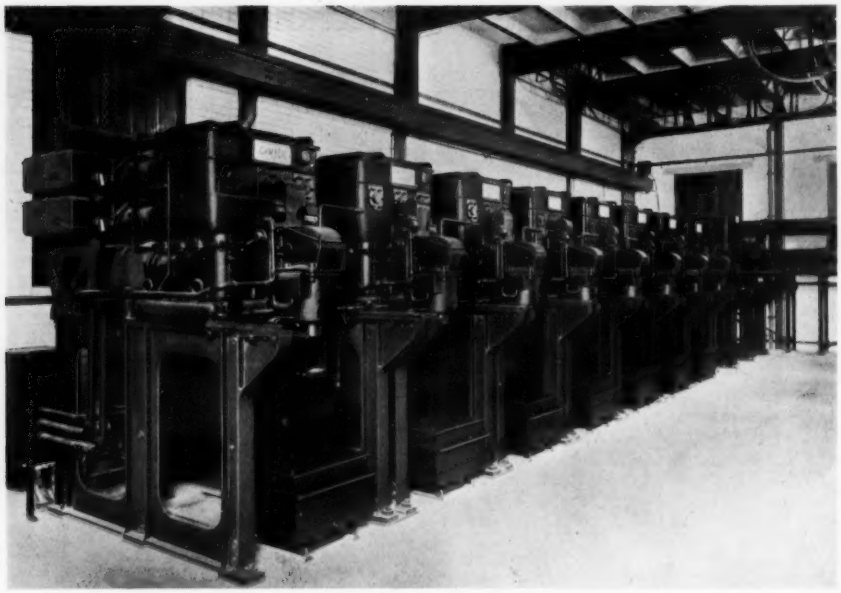


Fig. 2.—The North Group of Metal-clad units on the middle floor, and horizontal busbar trunks to the South Group.

Fig. 3.—The South Group of Metal-clad units on the Ground Floor, and vertical busbar trunks.

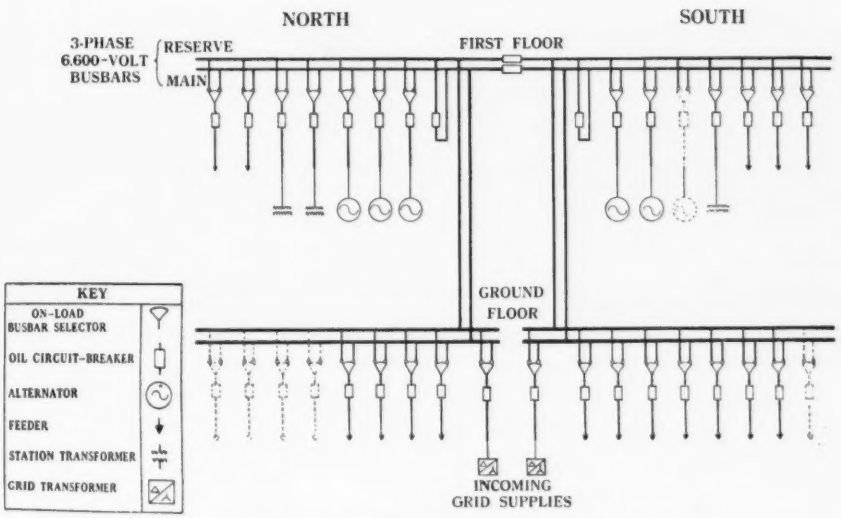


Fig. 4.—The Electrical Arrangement of the Metal-clad Switchboard.

the switching operations undisturbed by any noise or distraction from the turbine room. The whole installation has been constructed to the specification of Mr. Handley.

The switching equipment consists of twenty-eight units of the Company's compound-filled metal-clad type for operating at a pressure of 6,600 volts ; each unit has a rupturing capacity of 500,000 kilovolt-amperes, and is fully equipped with the necessary devices for the control and protection of the circuit to which it is connected. The principal parts of each unit are the fixed busbar chambers, supported on frames, and a three-phase oil-immersed circuit-breaker unit, which can, when desired, be isolated from the busbars by being withdrawn horizontally along slides carried by the side frames. There are two sets of three-phase busbars, and an oil-immersed selector switch in the upper part of the sliding portion enables the circuit-breaker, and the circuit which it controls, to be connected to either set of busbars, the transference being possible while the circuit is carrying current. All parts of the apparatus are fully interlocked and guarded, so that incorrect or unsafe manipulation is rendered impossible. The distinctive feature of this type of switchgear is that every part that is alive is encased in a strong metal enclosure filled with insulating compound or oil.

The switching units at Portsmouth are assembled together in groups so as to form two rows on each floor, with ample space on all sides for examination. Each of the units weighs approximately 6½ tons, and its oil circuit-breaker tank contains 100 gallons of oil. Control of the circuits by the opening or closing of the circuit-breakers is carried out electrically, so that in normal operation the rooms containing the switching units are entirely closed, and no attendant is present in them. The two rows of units on each floor and the groups on the two floors are connected by busbars enclosed in compound-filled iron ducts. Ample space has been allowed for extension of the boards when new generating plant is installed or new feeders are laid.

The most important part of one of the switching units is the circuit-breaker, which is closed by solenoid operating mechanism, and is designed to open automatically in the event of an overload or other disturbance on the circuit which it controls. When the circuit-breaker opens under such conditions, very high pressures may be produced within the oil tank, and it is therefore

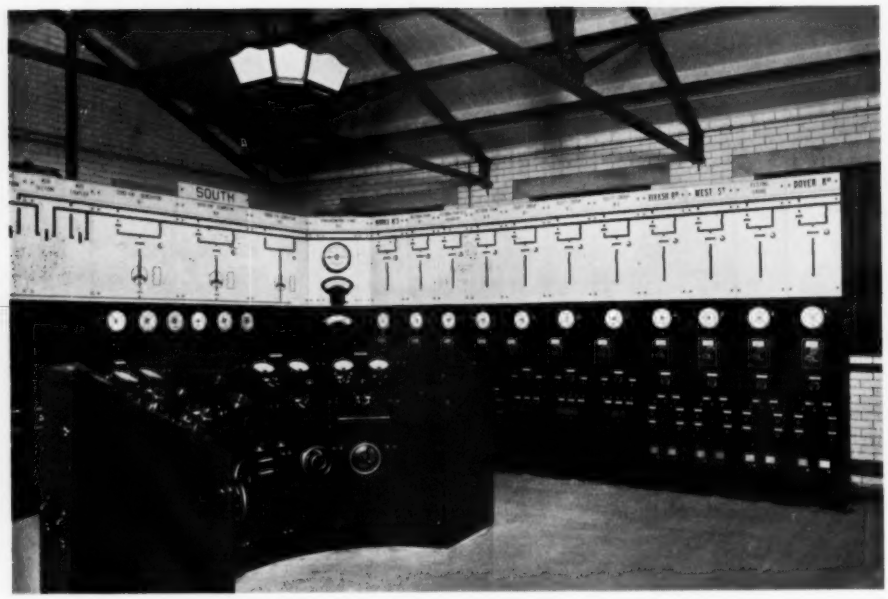


Fig. 5.—The Operating Desk and half the Main Control Board.

necessary to make this tank of heavy steel plate, and to secure it to the top frame in the strongest possible manner. The tanks on these units were tested with hydraulic pressure at the makers' works to 350 lb. per square inch.

The diagram on page 7 shows the electrical connections of the switching units, and the various circuits they control. It will be seen that five of the units control the power station generators, having a total capacity of 32,500 kilowatts, while other units control the feeders for public supply and power station auxiliaries; further units are for the purpose of isolating from one another the North and South groups into which the whole installation is divided, and others for controlling the connections between the duplicate busbars.

The control room on the third floor of the switch house contains a semi-circular desk type control board, by means of which the attendant can control the power station generators and communicate with any part of the system or power station by telephone or signal. In front of the attendant as he sits at the desk-type control board is a larger upright board which carries the control apparatus for synchronising, and for the feeder circuits, together with the necessary instruments. Running the whole length of this board along its upper part there is a diagram of connections of the switchgear with movable indicators which operate automatically, so as to show the attendant at any moment how the plant and various circuits are connected. The whole of the wiring and apparatus on this board is contained in a series of cubicles at the back, which are constructed of steelplate, and provided with access doors.

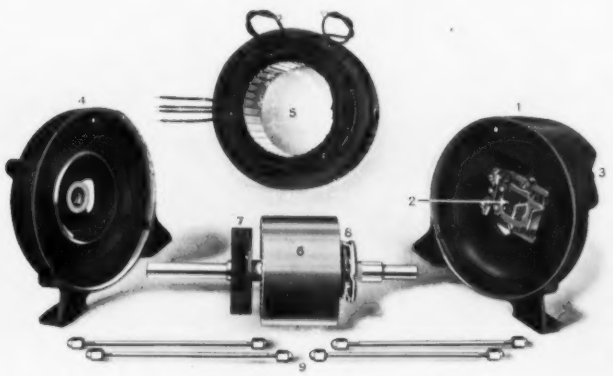
A separate compartment in the control room contains an accumulator battery for the supply of the control circuits, and a complete battery charging equipment is installed adjacent to the control boards. In order that the large quantity of oil used in the switching equipment may be maintained in proper condition, especially after any of the switches has operated under severe fault conditions, an oil purifying plant has been installed.

"English Electric" Fractional Horse-Power Motors.

For industrial drives of every description, including those which require special electrical or mechanical characteristics, the English Electric Company has for many years been able to place at the disposal of its customers a very full range of electric motors in all types of enclosure, for any method of driving, for extra-high starting torque, and for power factor compensation, up to the largest outputs required in heavy steelworks practice. The Company has now extended the range of these products by placing on the market self-starting single-phase motors of quite small powers, suitable for driving domestic and office appliances, as well as small industrial machines.

The L.F.1 motor illustrated in this article is of the split-phase squirrel cage type, provided with a reliable form of automatic switch that cuts out of circuit the starting winding as soon as the motor has run up to speed. This switch is of simple and strong design, and is operated by a centrifugal mechanism. The motor has no sliding contacts or commutator, and the rotor is practically indestructible. An ordinary tumbler switch can be used for control, and on switching the motor directly on to the line a starting torque of about one-and-a-half times full-load torque is obtained.

Other valuable points of the design are the provision of protected ventilated openings which give the characteristics of drip-proof enclosure, the fitting of a strong cast-metal fan, and a compact terminal enclosure sunk in the frame and enclosed by a protecting plate. The sleeve-type bearings are phosphor bronze of ample dimensions, and are packed with wool yarn in direct contact with the shaft; lubrication by a few drops of oil is required only at long intervals. As an example of the careful attention to detail mention may be made of the spherical shape of the caps that enclose the oil wells, this form having been found to obviate the collection of dirt or dust that is likely to occur on a flat surface. The shaft is of high tensile steel of ample section, and an extension with a machined flat is provided at one end for the pulley or other driving member.



1 & 4.—Stator End Shields; 2.—Centrifugally operated Switch; 3.—Terminal Recess; 5.—Stator; 6.—Squirrel-cage Rotor; 7.—Cast Metal Fan; 8.—Switch operating Device; 9.—Assembly Bolts.

In view of the necessity for good appearance and cleanliness in machines of this type a high-class black enamel finish has been given to the frames, and the external form has been considered as carefully as the technical requirements of good performance; the efficiency is high, the overload capacity adequate, and the temperature rise in accordance with modern standards. All parts are made to gauge to ensure interchangeability.

Oil-immersed Switch Fuse & Ring-Main Isolator.

There is general agreement that one of the most important directions in which electricity supply must develop in this country is that of providing services in areas that are sparsely populated, and that for this purpose the simplest and cheapest forms of distributing lines must be devised. The English Electric Company has given much attention to the need for new types of apparatus to control such distributing lines in rural districts, and has designed a wide range of appliances suitable for the various conditions which the distribution engineer has to meet. The control units described in this article afford cheap and efficient protection with a definite rupturing capacity for situations where the expenditure for an oil-circuit-breaker equipment would be uneconomic. For power transformers of medium kVA. the switch fuse gives ideal protection on the high-tension side against short-circuit conditions, leaving the protective apparatus on the low-tension side to take care of overloads.

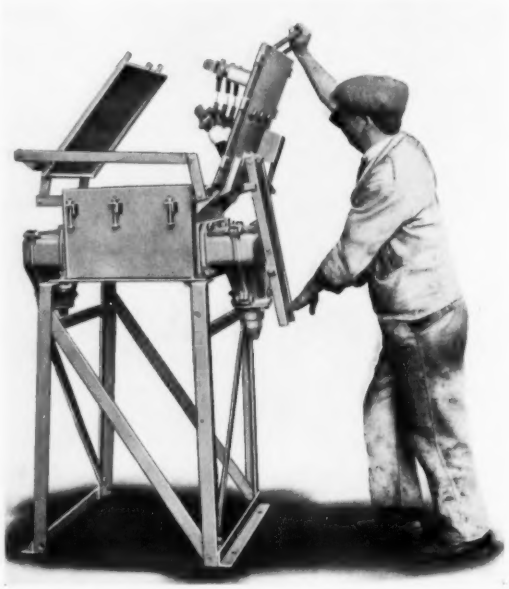


Fig. 2.—Opening the lid of the Switch-Fuse for examination of Fuses.

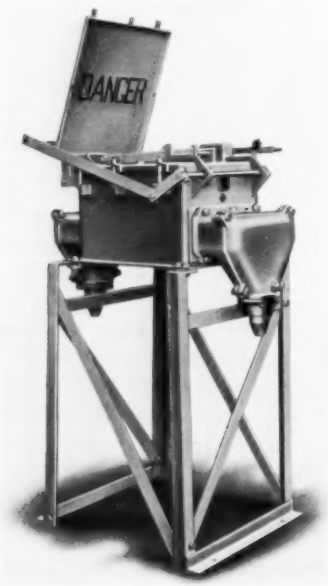


Fig. 1.—Switch-Fuse in Service Position.

The "English Electric" oil-immersed switch fuse consists of a steel plate tank with suitably spaced lining and phase barriers, with a fuse for each phase mounted between contacts fixed to the inside of a hinged lid; see Figs. 2 and 4. When the lid is closed in the normal working position

its contacts engage with fixed contacts carried by insulators secured to the sides of the tank, and when the lid is open the moving contacts and the fuses are out of circuit and clear of the oil. The special features of design which render the apparatus safe for manipulation under all conditions are described in detail later. The apparatus is suitable for use on pressures up to 33,000 volts, and fuse elements are available in a number of standard ratings up to 100 amperes normal carrying capacity. These fuse elements are complete units each consisting of two terminal plugs for inserting in the contact clips, and two spring-loaded plungers between which the fuse wire is held. This arrangement combines with a short length of wire, and therefore a small quantity of metal to be volatilised, a long clear break. Six spare elements are fitted in the lid, and no tool is necessary when replacing a blown element.

When it is desired to open the lid of the switch fuse for inspection or replacement of a fuse the isolating handle must first be moved to the "off" position; the fastenings are then loosened, and the lever which is normally folded flat on top of the lid is used for opening it to the vertical position, from which the movement can be completed by the aid of the handle at the edge of the lid. The action of opening the lid causes the protecting cover to close automatically over the top of the tank (see Figures 1 and 2), and access to the live contacts is thus prevented, and at the same time the oil is protected from dirt and moisture. As the automatic protecting cover can be locked in the "closed" position, the switch fuse may be used for isolating the circuit for any length of time.

Fig. 4.—Lid opened to show Fuses.

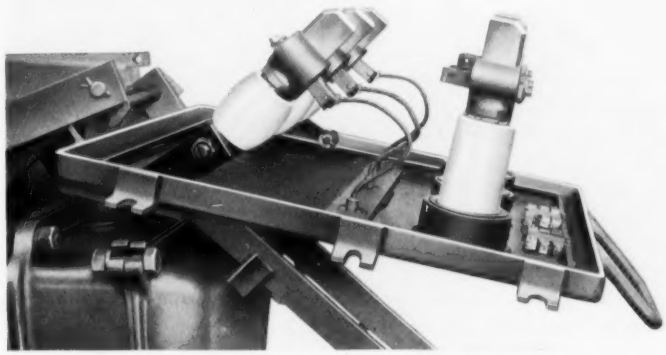


Fig. 3.—Fuses removed and Earthing Braids in position. The isolating contacts are in the "off" position.

An important feature of the apparatus is the isolating device mentioned above, which not only serves to break small currents, for example, 5 amperes at 11,000 volts, or 10 amperes at 6,600 volts, but contributes largely to the safe operation of the apparatus. The device is interlocked with the lid in such a way that the lid cannot be opened or closed until the isolating device is off, and the isolating handle

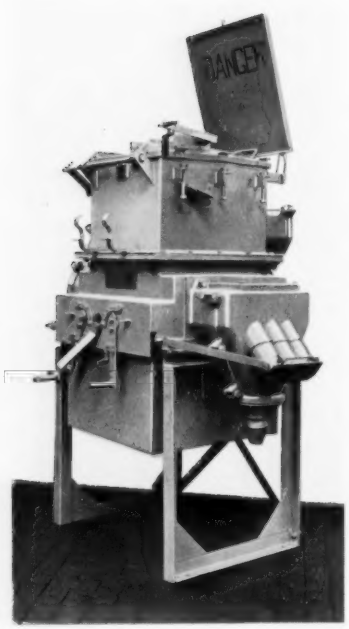


Fig. 5.—Oil-Immersed Switch-Fuse and Ring-Main Isolator; tank lowering handle inserted and cover over testing-opening in cable box.

cannot be moved to the " on " position until the lid is fully closed ; the position of the isolating handle is easily recognised by a clearly marked indicator. The switching movement of the isolators is brought about by mounting one set of three insulators, to which the fuses are flexibly connected by the spring plungers, on a shaft that can be rotated from the outside of the tank ; see Figs. 3 and 4.

Whereas certain types of switch-fuse have in the past failed to satisfy official inspectors, the interlocking device fitted as standard to " English Electric " oil-immersed switch fuses fully meets their requirements. Similarly the automatic protecting cover satisfactorily complies with the views of the Home Office by eliminating the risk that would otherwise arise, of an attendant leaving the lid open for the purpose of isolating the circuit and thereby exposing the live parts in the tank to accidental contact.

Special provision has been made in these switch fuses for earthing and testing the cables. Permanent earthing sockets contained in screwed plugs are provided inside the lid opposite each phase (Fig. 3), and in order to earth the circuit the fuses are removed, and a set of short flexible leads is connected at one end to the fuse sockets, while the other ends are plugged into the earth sockets ; by closing the lid, and then the isolator, earthing is completed. If it is desired to test the circuit the metal plugs in the lid which contain the earthing sockets are removed and replaced by three insulated terminals.

The arrangements for connecting the external cables are very flexible, and terminal bushings or cable boxes can be fitted in a variety of positions to suit the directions of the incoming and outgoing leads. If desired, two or more switch fuses can be assembled together to form a self-contained distribution assembly, and for this purpose compound-filled busbar chambers have been standardised for fitting underneath the units on either of the trifurcating box facings. These chambers are self-contained, and are con-

Fig. 6.—Cover over testing-opening in cable-box open for inserting of testing plug.

nected together by clamping muffs between adjacent units, while the extreme ends are closed by suitable covers. The busbars pass through slots in paxolin plates which serve to support

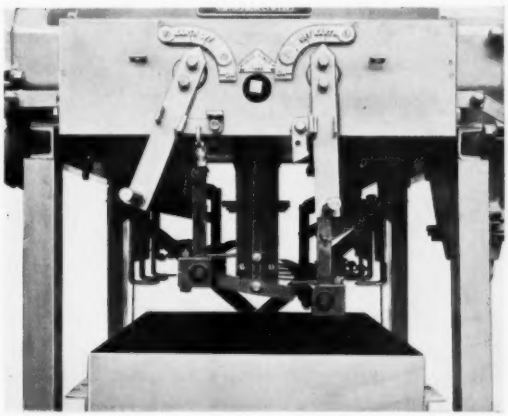


Fig. 7.—Ring-Main Isolator with tank lowered, left-hand switch off, right-hand switch in "earth" position.

them. It will be clear from the illustrations that the switch-fuses can be mounted on unit type frames to bring them to a convenient height.

A ring-main isolator equipment has been developed for use in conjunction with the oil-immersed switch-fuses in order to extend their field of application. Whereas the switch-fuse by itself can be used to control transformers at outlying points at the ends of feeders, the ring-main equipment enables a series of substations to be joined up into a ring. An important advantage of the equipment is that the isolators are capable of breaking the full-load current, and therefore the ring main may be interrupted at any point irrespective of whether current is flowing through that point or not. This is a considerable improvement over similar devices which can be operated only when the load is off. As will be seen from Figs. 5 and 6, the ring-main cables are led from above or below into each side of the unit and the circuit passes through the isolating switches to a centre contact, from which is taken the "tee-off" to the switch-fuse. The connections from the cables and the switch-fuse are enclosed in a compound-filled chamber.

The isolating switches are of the laminated brush type giving a double break, and have auxiliary sparking contacts with easily renewable tips. The moving contacts are mounted on paxolin tubes, and the connections between the two compartments are through porcelain insulators. Each isolator has three positions, namely, "on," "off," and "earth," and the earth circuit is made by separate spring contacts; these details of the design are shown in Fig. 7.

The operating handles of the isolators can be padlocked in either of the three positions, and the position of each switch at any moment is clearly shown by an indicator. A catch is fitted to prevent the line being earthed accidentally, when it is desired to move the switch only as far as the "off" position. Each unit is complete with a tank-lowering device, which is interlocked with the isolators in such a way that both must be in the earthed position before the tank can be lowered. Once the tank has been removed it is possible to close either or both isolators to inspect the contacts and adjust the sparking fingers if necessary. In each cable box three-phase testing sockets are provided, which are accessible through an opening covered by a shutter, as shown in Figs. 5 and 6. These shutters are interlocked with the respective isolating switches in such a way that the switch must be in the earthed position before the shutter can be raised for inserting the test plugs. Moreover, it is impossible to close the isolator when the shutters are held open either by the presence of the testing plugs or otherwise. The plugs are of watertight design in order to prevent the entrance of moisture.

"English Electric" ring-main isolators are made for use on systems up to 11,000 volts, and in two standard sizes rated at 200 amperes, and 400 amperes respectively.

Steam Turbo-Generating Plants for Small Outputs.

This article outlines the current practice of the Company in constructing steam turbine plant for the range of outputs that meets the needs of most industrial power stations. Their designs include, in addition to high-pressure turbines, turbines for providing process steam and for mixed-pressure operation.

In addition to the large multi-cylinder and single-cylinder turbo-alternator sets made by the Company for main central stations, they have specialised in the production of complete generating units suitable for factories and other power plants of comparatively small size, such as those on board ship.

To reduce the cost of installation and of working and to secure a general simplification of the power house arrangements, a line of self-contained turbo-generators has been developed which is capable of adaptation to a wide variety of local conditions. The aim has been to arrange the whole of the plant with the condenser and its auxiliaries as a compact self-contained unit, which does not require the excavation of a deep basement.

When the conditions are suitable the condenser is mounted at floor level, and the turbine exhaust is coupled directly to it as shown in Fig. 1 and in the diagrams Figs. 3 and 4. It will be seen that the extraction pump for the condenser is driven mechanically from the low-speed shaft, and the circulating water pump is coupled directly to one end of the unit. This design does away with separate auxiliaries with their motors, cabling and low-tension electric supply, and the whole of the electrical output of the set is available for the main purpose of the plant.

Not only is there a considerable saving in the cost of foundations, erection and pipework, but there is also a gain in operating economy by reason of the simpler supervision and maintenance and the reduction in the number of separate items requiring attention.

In designing their surface type of turbo-generator sets The English Electric Company has taken particular care to avoid sacrificing in

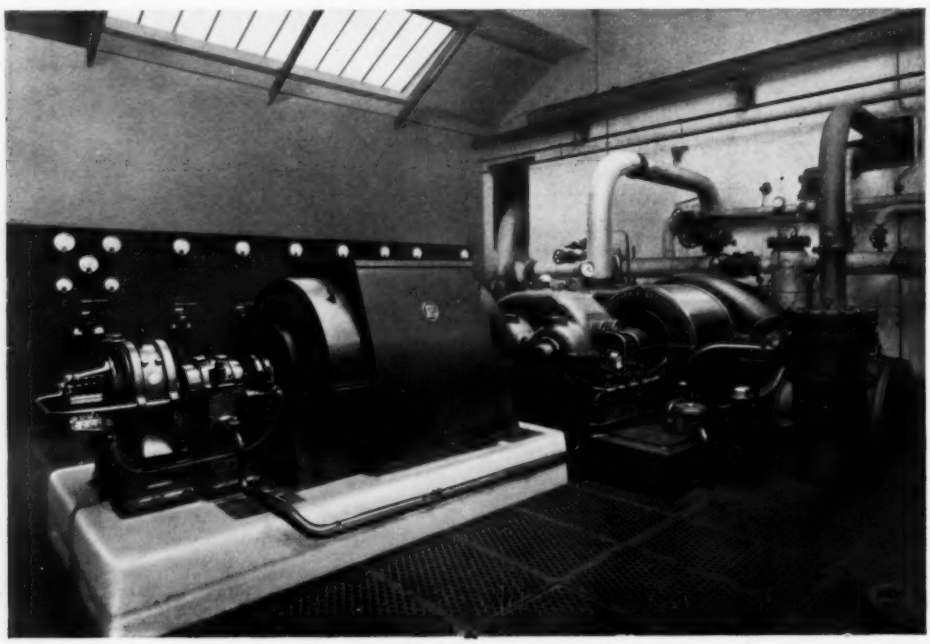


Fig. 1.—Surface-type geared Turbo-alternator set in a Textile Mill.

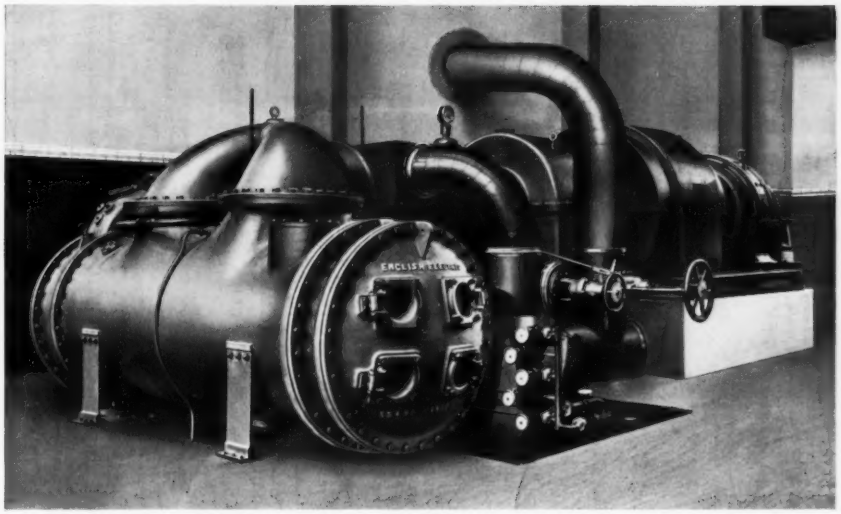


Fig. 2.—Surface-type Plant for D.C. and A.C. supply in an Electricity Works.

any way the reliability associated with their sets of more conventional design, which are in operation in factory and other power houses throughout the world. They have drawn on their long experience in the design of steam turbines up to the largest sizes and have avoided the introduction of any untried or complicated features.

The Turbine Experimental Laboratory at the Company's Rugby Works has made valuable contributions to the study of nozzle and blade forms and in other directions, and is fully equipped for carrying out the scientific and practical tests that are essential to the progressive development of reliable high efficiency steam turbines. The results of the investigations have been embodied in the small plants, so that high efficiency is obtained without impairing their reliability.

" English Electric " Self-contained Turbine Plants have the following important advantages :—

Cheaper Power House Buildings. The excavation of a deep basement for the condenser is unnecessary and as the loading on the foundations is much reduced they are both simpler and cheaper. The arrangement of the gear and other parts facilitates erection or dismantling and permits the building to be somewhat lower.

Simpler and Cheaper Erection.—The self-contained nature of the plant and the compact layout on one level reduces the number of parts to be handled, and also the number of mechanical and electrical connections to be made on site.

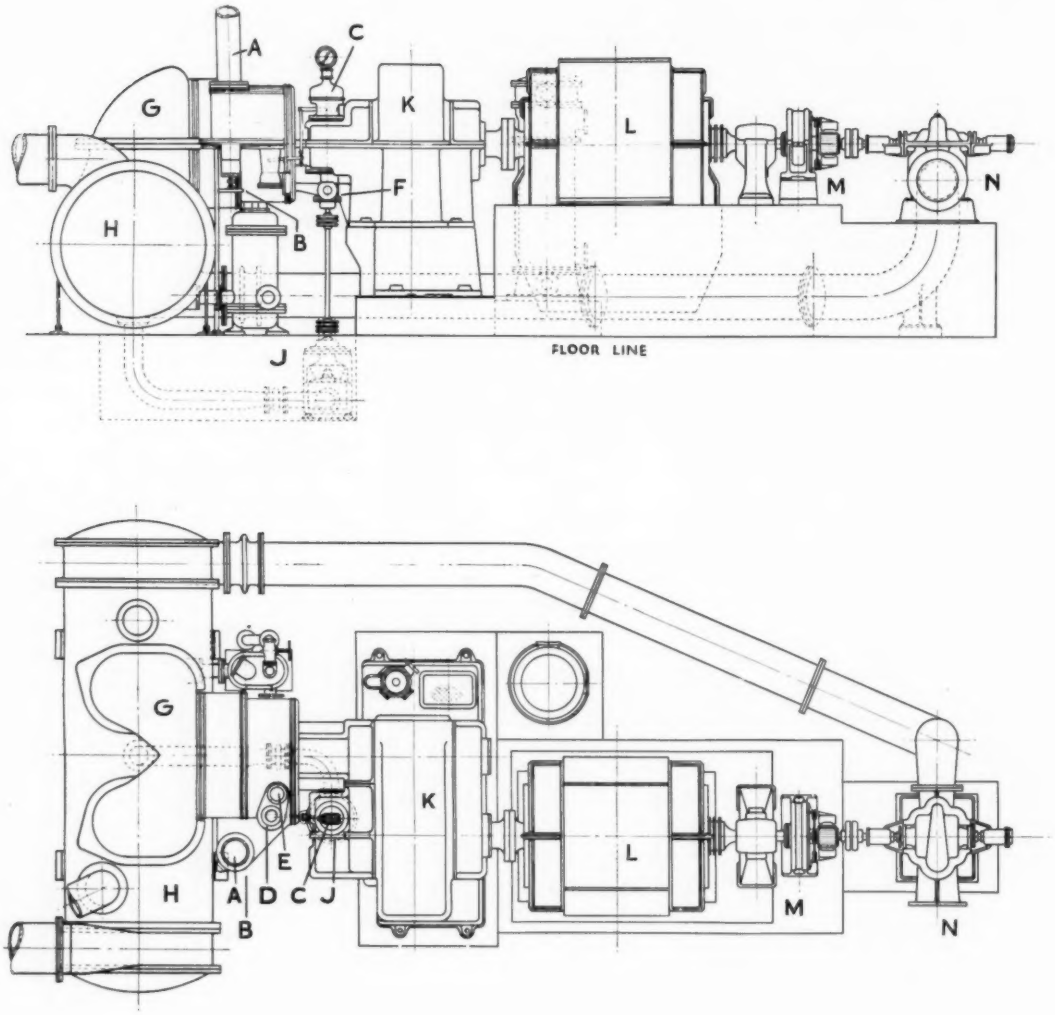
More Economic Operation and Supervision.—All parts are readily accessible and visible from one level and the auxiliaries require practically no special attention.

Minimum Maintenance and Great Reliability.—Every portion of the plant is of rugged construction and the operation of the set does not depend on separate auxiliaries. The maintenance of the vacuum is independent of any electrical supply.

Rapid Starting Up.—These sets can be run up and put on load very quickly by the operation of the valves alone, without the necessity of having to operate control gear on separate auxiliaries.

The principal features of the design of the " English Electric " self-contained non-basement turbine and condenser assembly are shown in Fig. 3. The most important of these are :—

Exhaust end of turbine and condenser inlet built compactly together ; very smooth flow of exhaust steam into condenser ; extraction pump driven by gearing ; high speed pinion mounted



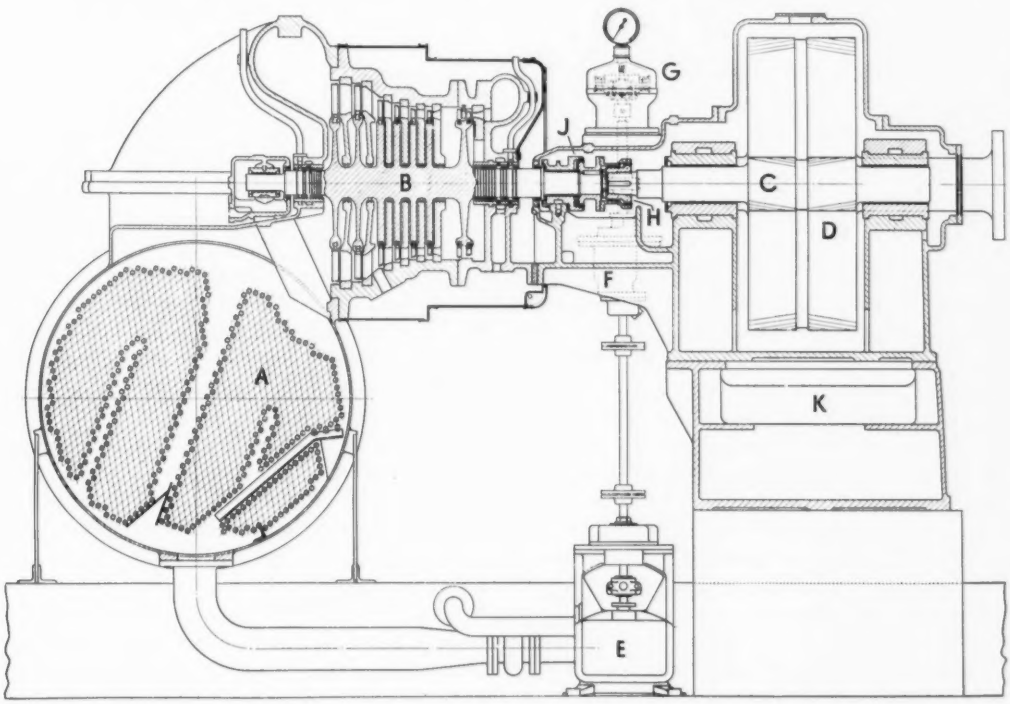
A—*Steam Supply Pipe.*
B—*Stop Valve.*
C—*Governor.*
D—*Throttle Valve.*
E—*Overload Throttle Valve.*
F—*Oil Pump.*
G—*Exhaust.*
H—*Condenser.*
J—*Extraction Pump.*
K—*Reduction Gear.*
L—*Alternator.*
M—*Exciter.*
N—*Circulating Water Pump.*

Fig. 3.—General Arrangement of "English Electric" Surface-type Turbo-generating Plant.

at side of low speed gear wheel to facilitate erection, and inspection, without dismantling any other portions of the turbine or generator; condenser and exhaust end of turbine supported flexibly to permit free expansion of all parts; circulating water pump driven directly from generator shaft (when desirable on account of local conditions a separately driven pump can be used); rotor wheels an integral part of the rotor forging.

The turbines are designed for speeds of from 4,500 r.p.m. to 7,000 r.p.m. according to the output, and in accordance with the Company's long experience as to the most suitable form of construction an impulse type of turbine has been adopted with a velocity compounded stage embodied at the high-pressure end. With this design ample clearances can be combined with high efficiency and a safe and reliable unit results.

The Turbine Casing is built up in three sections forming the high-pressure and low-pressure portions and the exhaust chamber, and in addition the entire casing is divided horizontally into upper and lower halves. The upper half of the high-pressure section, containing the steam chest and nozzle chamber, is the only portion of the casing subjected to the full pressure and temperature, and it is accordingly made of cast steel, which is used also for the corresponding lower half. The low-pressure portion of the casing is of cast iron of special composition suitable for withstanding the temperature and pressure conditions without distortion. At the exhaust end



A—*Condenser.* C—*High-speed Pinion.* F—*Oil Pump.* J—*Michell Thrust.*
B—*Turbine Rotor.* D—*Low-speed Gear Wheel.* G—*Governor.* K—*Oil Reservoir.*
E—*Extraction Pump.* H—*Flexible Coupling.*

Fig. 4.—Details of Surface-type Turbine, Condenser and Gearing.

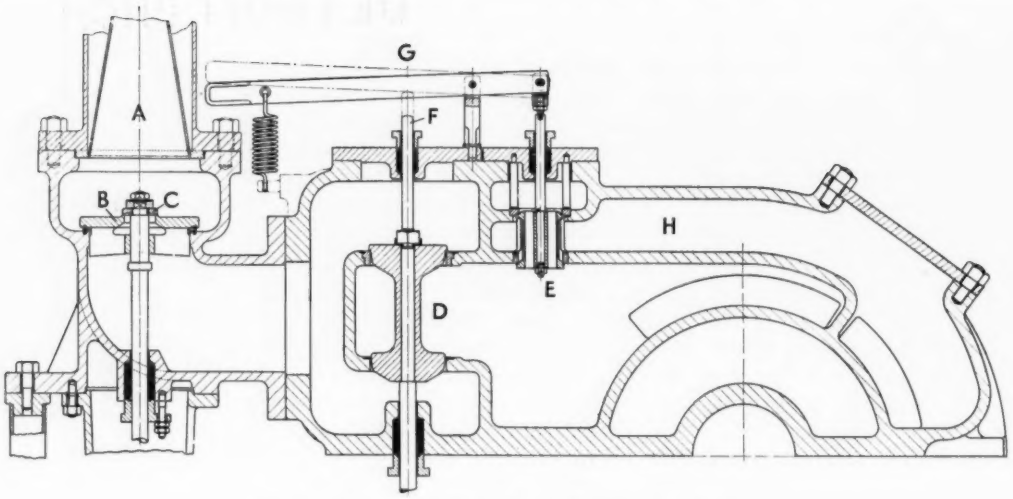


Fig. 5.—Diagram of Main Steam Passages and Valves.

cast iron is used for the top casting and cast steel for the lower half, which forms the condenser inlet piece. Steam enters the turbine through the main stop valve, control valves and nozzle chamber ; the valves and their operation will be described later in association with the governor gear.

The nozzles, through which the steam enters the high-pressure stage, are of the built-up type accurately machined and arranged in two groups to which steam is admitted under the control of the governor and throttle valves.

A solid forging of high-quality steel is used for the turbine rotor. From this the discs that carry the moving blades are turned out of the solid so that they are integral with the shaft. The forging is carefully annealed both before and during the processes of machining, and this construction is the same as is used in the Company's largest turbines. For the larger size of the range separate wheels may be used for one or two of the lowest pressure stages. The number of stages depends upon the output, and the steam and vacuum conditions.

The rotor blades are fixed to the periphery of the wheels by means of T roots fitted accurately into grooves ; they are machined from solid bar, and are of such a form as to give ample strength. The blading is supported in batches on the outer periphery by shrouding which forms, also, an outer boundary to the steam passages.

The diaphragms for the low-pressure stages are constructed of cast iron with steel blades cast in to form the steam passages. They are split on the horizontal joint diameter to facilitate removal of the top half of the casing for inspection. Each half diaphragm is fitted into a groove machined in the casing, and the horizontal joints are formed with keys to obtain an accurate register and steam tightness. The inner bore of the diaphragms is fitted with labyrinth glands to prevent leakage of steam from one stage to the next.

The shaft glands are of the labyrinth type both at the low-pressure and high-pressure ends of the turbine casing, the labyrinth being formed by baffle strips fitted into grooves in the gland bushes. These baffle strips are of a copper alloy with a sharp edge, and are so arranged as to give the necessary clearance over the shaft. There is no necessity for adjustment, nor for a supply of water either for cooling or for sealing.

The thrust block is of the Michell type, so arranged that the clearances between the fixed and moving portions of the turbine are kept constant under all conditions. The surfaces of

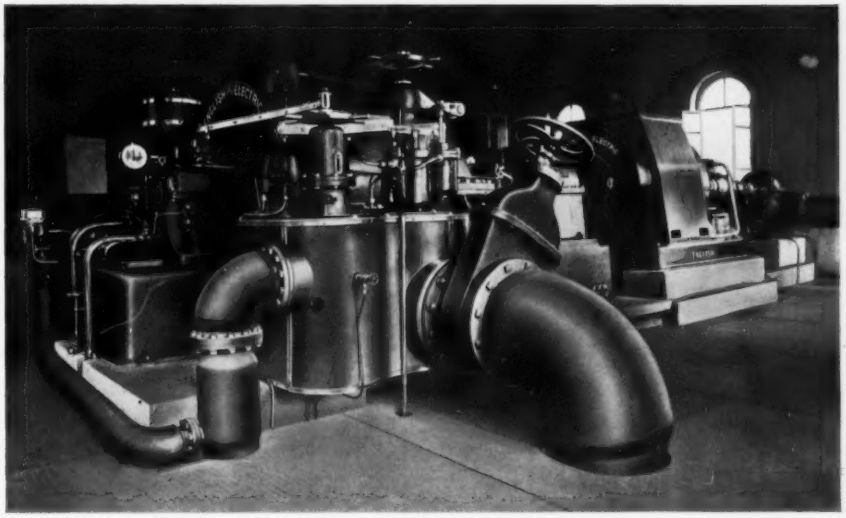


Fig. 6.—1,200 kW. Mixed-pressure Set in an Industrial Works.

the block are of ample capacity, as the amount of end thrust with an impulse type turbine is practically negligible. Further, it is freely lubricated by oil under pressure from the main lubricating system.

The bearing shells for supporting the turbine rotor are of cast iron lined with whitemetal of a special composition.

Oil enters the bearings under pressure at both sides, thus providing a supply of oil for lubrication and a further supply for cooling of the bearings, this oil supply being from the main lubricating system.

Fig. 6 enables the course of the steam to be traced from its entry to the main stop valve through the conical strainer A. The main stop valve B, which is hand-operated, unless it is closed automatically by the overspeed tripping device described later, contains a pilot valve C; when the hand-wheel is turned to open the stop-valve, steam is admitted first through the pilot valve thus balancing the pressure across the main valve throttle, and building up gradually the pressure applied to the turbine.

The steam then passes through the main throttle valve D, which has been opened by the oil in the relay cylinder K (see Fig. 9), under pressure from an auxiliary pump driven by a small steam turbine. Valve D and the overload valve E are under the control of the governor. When D has opened nearly to the full extent a stem F comes into contact with lever G, and further opening of D (due to increasing load) causes the auxiliary throttle E to open and admit steam to the overload nozzle H. The steam chest containing these valves is embodied in the cast-steel top half of the high-pressure end of the casing, thus forming a very compact and rigid construction.

The governor is of the standard "English Electric" design and is very sensitive and thoroughly reliable. It does not operate the main throttle valve D directly, but actuates a small pilot valve J (see Fig. 9) which controls the oil pressure in the relay cylinder K, and the piston in this cylinder moves the throttle valve. L is a floating lever under equilibrium and M a small handwheel for regulating the speed.

In the same diagram is shown the oil pump N that furnishes the pressure oil to the bearings and governor gear. P is the main drive from the low speed gear shaft and Q the drive to the extraction pump.

Provision is made for automatic closing of the main stop valve in the event of the speed of the

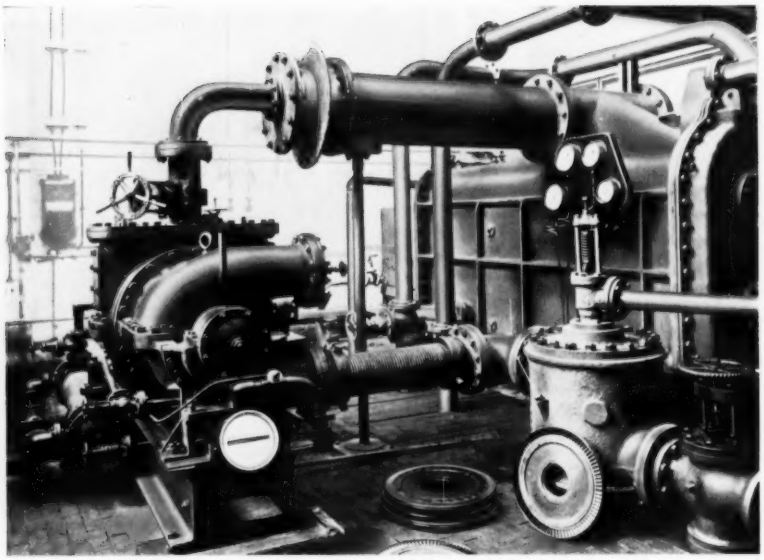


Fig. 7.—Experimental Turbine Plant in the Company's Research Department.

Fig. 8.—The General Laboratory in the Research Department.

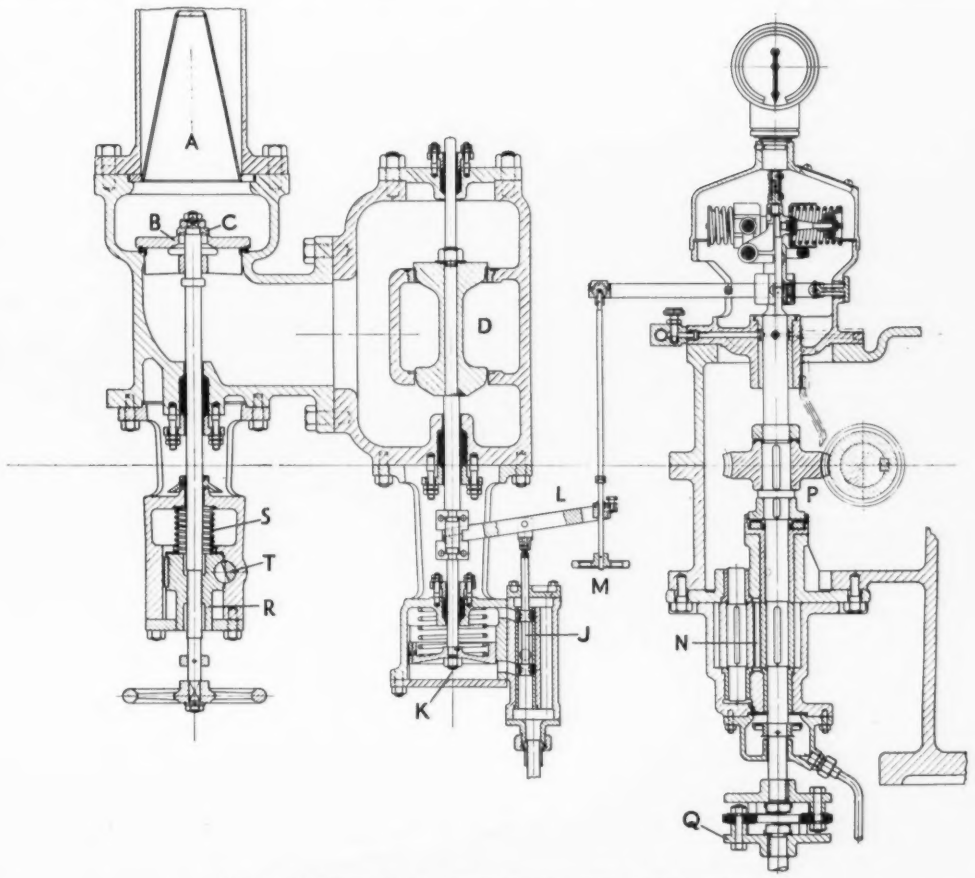


Fig. 9.—Diagram of the Governing and Steam Control System.

turbine rising above a predetermined limit, say 10 per cent. above the normal speed. Referring to Fig. 9, the axial movement of the stop-valve spindle is due to its rotation in the threaded sleeve R which is held in the normal position shown, against the pressure of the spring S, by the rotatable pawl T.

Pawl T is coupled to the small lever U, see Fig 10, which is held in the normal working position, as shown, by oil pressure in the cylinder V. The device is under the control of the ring type emergency governor W ; when the outer ring is displaced eccentrically on the occurrence of excessive speed, lever X is moved to the dotted position, thereby releasing trigger Y and thus causing pilot valve Z to move to the left under the action of the compression spring AA. The pilot valve cuts off the oil pressure from the relay cylinder V, and releases the oil in it to exhaust ; consequently lever U moves up and pawl T (see also Fig. 9) releases the threaded sleeve S which is forced down by the spring, thus closing the main stop valve ; when closed, the valve is held tightly down to its seating by the steam pressure above it.

The oil pump, which is of the gear type, delivers oil at a pressure of 40 lb./sq. in. for operating the relay cylinder of the governor gear, and also supplies oil to the bearings at a pressure of 5 or 10 lb. per sq. in., this reduced pressure being obtained by a hand-controlled valve. The

pump draws its oil from the main reservoir, and forces it through the cooler to the turbine, bearings, and gearing. The reservoir from which this oil is obtained forms the support for the gearbox.

In addition to the main oil pump, an auxiliary oil pump of the steam driven turbo-centrifugal type is fitted, the capacity of which is sufficient to supply oil for running the set. It is also used when starting up or shutting down, and is arranged to start automatically should the oil pressure for any reason fall below a predetermined limit. On the smaller sets a hand-operated auxiliary oil pump is provided.

It will be seen that a second safeguard is provided by connecting the oil-pressure relay cylinder K of the main throttle valve to the emergency pilot valve Z. If the latter is actuated, due to overspeed, the main throttle valve also closes immediately.

Resetting of the emergency pilot valve is effected by pressing knob BB. The emergency trip can be actuated by hand by pressing knob CC.

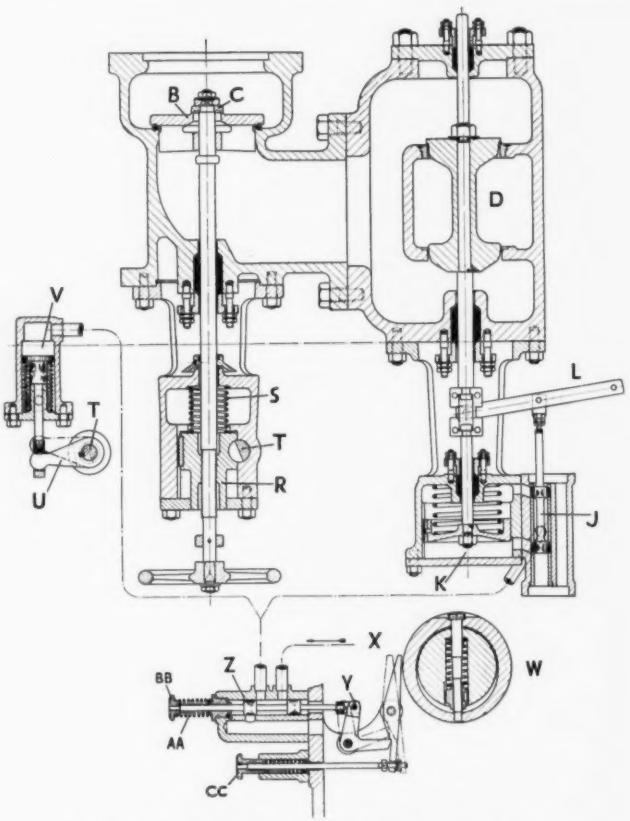


Fig. 10.—Diagram of Overspeed Tripping Device.

An oil cooler of the tubular type is provided, with brass tubes expanded in brass tube-plates, the cooling water passing through these tubes and the oil flowing around their outer surface in a zig-zag path, directed by means of suitable baffle plates.

The coupling between the turbine shaft and pinion is of the single-sided flexible tooth type that has given excellent service on the Company's turbines of all sizes. It is provided with forced lubrication.

The general design of the condenser is based upon the Company's long experience in the manufacture of this type of plant, but the details have been carefully adapted to conform to the special design of the whole unit. The shell is of mild steel plate and the inlet piece from the turbine is in the form of a cast-steel saddle welded to the shell. The water boxes are of cast iron with mild steel end covers and the tube plates are usually of mild steel. As previously mentioned the position of the condenser in relation to the turbine, and the form of the exhaust end of the latter are such as to ensure smooth flow of the steam with minimum loss of energy. The method of supporting the condenser in a manner that permits free expansion in every direction is both simple and efficient; it consists of mild steel plates bolted to pads that are welded on to the shell.

The manner in which the pumps are driven mechanically has already been described and illustrated. In some cases it is more convenient to use a separate motor-driven pump for one or both of these services, and this can be done without affecting the main features of the non-basement design.

FRACTIONAL HORSE POWER

ENGLISH ELECTRIC COMPANY LTD.

Queen's House, Kingsway, London, W.C. 2.

Works: BRADFORD, PRESTON, RUGBY, STAFFORD

The Application of the Induction Voltage Regulator.

(This paper, read before the Institution of Electrical Engineers last year by Mr. W. E. M. Ayres, M.I.E.E., is reprinted in an abbreviated form (with additional illustrations) because it is felt that the subject is of great importance to the electric supply industry. Better voltage regulation leads not only to more satisfied consumers, but also to lower cost of distribution and fuller revenue.—EDITOR.)

(*Concluded from Vol. V. No. 8*)

It may be noted also that by increasing the voltage at the sending end the maximum kVA, or "pull-out-point" of the line, is increased as the square of the voltage, as may easily be seen from a transmission-line circle diagram, apart from any advantage gained by the smaller amount of reactive kVA transmitted. The line therefore works with a better regulation, which may be of considerable importance if the starting of rotating electrical machinery has to be undertaken at the receiving end.

Where there is a tapping from the feeder close to the sending end, there is a danger that consumers connected to the tapping may receive a voltage higher than is permissible at periods of heavy load. Two courses are open—either the regulator may be placed on the far side of the tapping from the power supply, or a separate, smaller regulator may be placed in the branch at the tapping point. The choice is purely an economic one which can only be decided by site conditions and relative costs of the regulators required.

Where bulk supply is taken by a distribution authority a larger voltage variation is allowed by the existing supply regulations than can be passed on to the consumers. In almost all such cases the first problem is to control the voltage on the distribution busbars. When these distribution stations were small, independent generating stations a fair degree of satisfactory service was given by systematically raising the busbar voltage as the station load increased. This compromise is easily achieved under the new (unattended) conditions by using automatic induction regulators and adding line-drop compensators as a compounding device. If the distribution is not extensive this arrangement may be found to fulfil the requirements, but if there are outlying feeders for more remote rural areas it is an advantage to equip these with additional regulators.

One of the principal causes of severe voltage variation on low-voltage distribution systems is the heavy peak load of existing domestic appliances. Thermal-storage water heaters are on the market in abundance, but are not used to the extent that they deserve, whilst thermal-storage cookers are unknown in this country. Load-levelling and improved load factor are the questions of paramount importance at the moment to the electricity supply industry. At present ordinary domestic cookers are installed capable of taking a peak load approximating 8 kW., and with single-phase 3-wire, or 3-phase 4-wire, distribution the voltage disturbance is

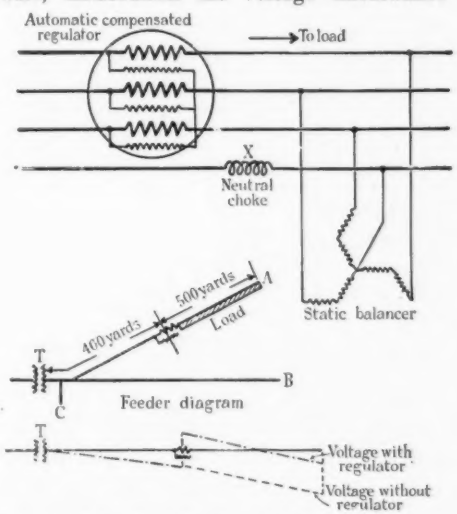


Fig. 14.—Typical application of induction regulator and static balancer to low-tension distributor.

accentuated by the drop in the neutral conductor due to the out-of-balance load.

A particular instance, which is typical of numerous cases to be found throughout the country, will be quoted to illustrate the diffi-

culties to be overcome and the application of an induction regulator to correct the voltage variations. In Fig. 14, T represents a 100-kVA transformer substation from which radiate three low-voltage distributors (3-phase, 4-wire) on a 400/230-volt system. The three underground cables are of 0·05 sq. in. with a neutral of 0·025 sq. in. Along branch A there was no load for 400 yards as the road ran alongside an open space, but this was followed by 500 yards of good-class residential property, all having electric light with small domestic appliances, and the majority having radiators and cookers. The voltage at the end of the 900 yards showed a voltage variation, by recording voltmeter, from 186 to 263 volts. An induction regulator, with static balancer on the load side of the regulator, was placed at the commencement of the loaded portion. The regulator was compensated for line-drop so as to give a constant-voltage load centre about half-way along the loaded portion. Tests on this installation showed that 7 kW (30 amps.) out-of-balance load on any one phase gave only 14 volts maximum variation from declared pressure at any of the consumers' terminals. Complaints about voltage from the consumers on this section completely ceased.

The use of interconnected star balancers (and mid-point balancers on single-phase, 3-wire distribution) has often proved advantageous. By eliminating the neutral drop between the point of application of the regulator and the transformer, a smaller amount of voltage correction, and therefore a cheaper regulator, is required. It has sometimes been stated that if the neutral point of the regulator primary windings is connected to the neutral of the supply, the regulator itself will restore a voltage balance to the system. Experience and a small amount of calculation shows this to be erroneous. In the first place, the balancing effect of the regulator windings is in parallel with that of the transformer itself, but the impedance of the regulator windings is enormously higher than that of the transformer and distribution cables. The result is that the regulator contributes practically nothing towards balancing. Further, the normal primary current is frequently small when compared with the out-of-balance current. For instance, in the typical case cited above, the out-of-balance current may be more than 30 amps., whereas the primary full-load current is only 8 amps. As static balancers are much cheaper per kVA than induction regulators, it is obviously cheaper to limit the regulator to its legitimate functions.

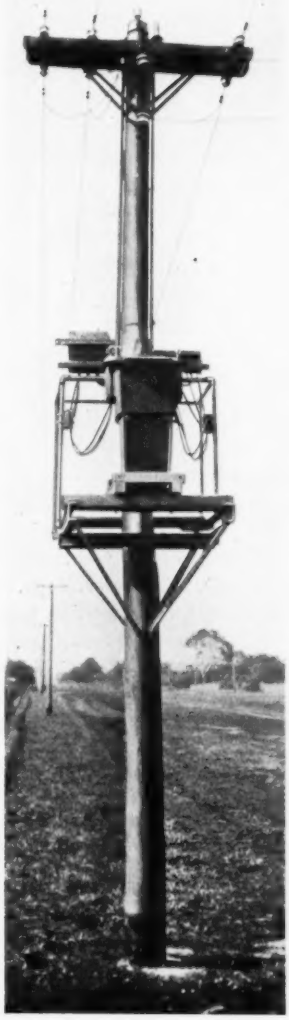
Even where a static balancer is used there is a tendency for the transformer to share the balancing of the loads in inverse proportion to the impedance of the circuits, unless special precautions are taken. As it is not permissible to earth the neutral at more than one point, it is essential to carry a continuous conducting neutral throughout the system. To break the neutral conductor at the balancer would prevent the transformer from sharing the balancing, but might set up earth currents and is not permitted. The English Electric Company have overcome the difficulty by inserting a special choke coil in the neutral conductor immediately before the balancer, as shown at X in Fig. 14.

Economical Considerations.

In the typical case (Fig. 14) the only alternative to the use of an induction regulator was a considerable increase in cable size for the distribution main. It was found that to give satisfactory service within the prescribed limits of voltage allowed this would cost, with laying and reinstatement of road, approximately £780, whereas the cost of a fully automatic regulator, complete with static balancer and kiosk, was in the neighbourhood of £185, which shows a very great saving in favour of the regulator.

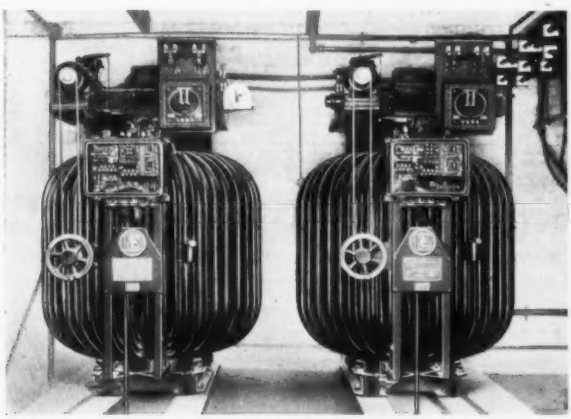
As a further example let us compare (see Table) the costs of a regulated and unregulated transmission line 3-phase, 50 cycles, 11,000 volts, to deliver 3,000 kVA over a distance of 12 miles. The load factor has been taken as 18·75 per cent. on a basis of 2 hours per day at full load, 2 at $\frac{3}{4}$ load, 2 at $\frac{1}{2}$ load, and 2 at $\frac{1}{4}$ load, with the remaining 16 hours at no load. Such a cycle is close enough to actual working conditions for a mixed load to make the comparison useful.

Distribution of small amounts of power to a residential colony or small village show the same economy from the use of voltage regulation.

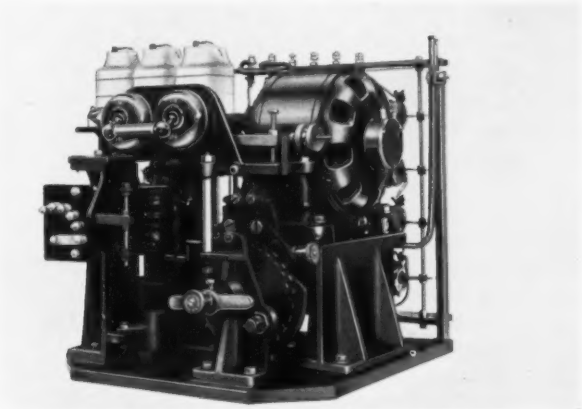


Pole-mounted Automatic Regulator in service on a 400-volt, 3-phase Feeder in Australia.

A group of Twin Regulators for 440-volt, 3-phase Feeders in a London Borough.



Two Automatic Single-phase Regulators giving ± 10% Regulation of a 6.6 kV., 3-phase Feeder.



Operating Gear for Small Automatic Induction Regulator.

TABLE.

	Regulated line.	Unregulated line.
Size of conductor	0·10 sq. in.	2 of 0·20 sq. in.
Cost of line per mile	£760	£2,100
Total cost of line	£9,120	£25,200
Cost of 300-kVA regulator to correct ± 10 per cent. variation from normal voltage	£880	—
Capital cost	£10,000	£25,200
8½ per cent. on ditto	£850	£2,140
Transmission line losses per year (kWh)	480,000	120,000
Regulator losses per year (kWh)	40,000	—
Total losses per year (kWh)	520,000	120,000
Cost of losses at 0·50d. per kWh	£1,082	£250
Annual cost	£1,932	£2,390
Voltage-drop at full load, 0·8 power factor	0	7·6 per cent., or ± 3·8 per cent. from declared pressure.

Assume that it is required to supply up to 50 kVA (70 amps.) to such a colony 1,000 yards beyond the limits of the existing low-voltage distribution. Should this be by means of a high-voltage line from the last transformer substation, or by an extension of the present distribution with an automatic voltage regulator?

Cost of 1,000 yards of 0·05 sq. in. 400/230-volt overhead line	£245
Cost of 5-kVA pole-type induction regulator	£135
Cost of auto-transformer to step-up voltage so as to utilise buck and boost of regulator	£18
Total	£398
Cost of 1,600 yards of 6·6-kV overhead line	£275
Cost of transformer, kiosk and switches ...	£230
Total	£505

Possible extensions of load will have to be taken into account, but the above represents a typical case frequently met with in suburban or rural areas.

The cost of transmission equipment and balance of losses is, however, not the whole of the case for voltage regulation. Electrical energy used for motive purposes is not very sensitive to small voltage-changes, but electrical energy used for lighting and heating, as in most domestic appliances, is extremely sensitive to voltage change and the loss of revenue due to reduced voltage is seldom appreciated. The watt consumption of modern lamps is reduced by 1·5 per cent. for each 1·0 per cent. reduction in voltage, whilst the reduction in life of the lamps is very considerable for quite small over-voltage. Heating appliances have a watt consumption practically proportional to the square of the voltage. Fig. 15 shows a typical winter-day domestic load curve as it would be at declared pressure and as it actually is with 10 per cent. reduced voltage at full load. The shaded portion represents dead loss of revenue which can be largely avoided.

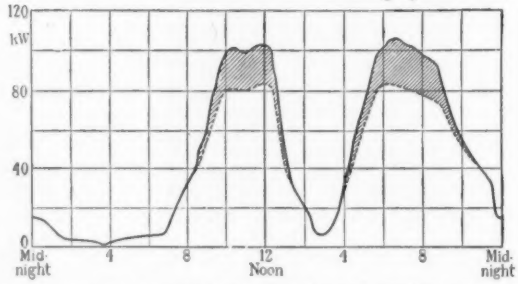


Fig. 15.—A domestic load curve for a winter day. Shaded portion represents lost revenue occasioned by a 10 per cent. voltage-drop.

Now there are two aspects of domestic load which make this waste of revenue very seriously uneco-

nomical. In the first place, domestic consumption is a high-priced load because of the low load factor and high cost of distribution. On the other hand, the load represented by this lost revenue could be supplied without any additional plant (except the automatic regulator, which we have found to be frequently an economy in itself) and, therefore, could be supplied at fuel cost.

Load Control.

The control of an open interconnector between two generating stations is a fairly simple matter. The load-sharing is controlled by the governors of the prime movers, and wattless transfer is controlled by generator excitation or by voltage regulation in the interconnector itself. The control of a loop, or closed, interconnector joining two or more generating stations with load tapped off on either side of the loop is a very different proposition. In the case of the open interconnector the angular position of the generator fields may have any relationship which the resistance and reactance constants of the line

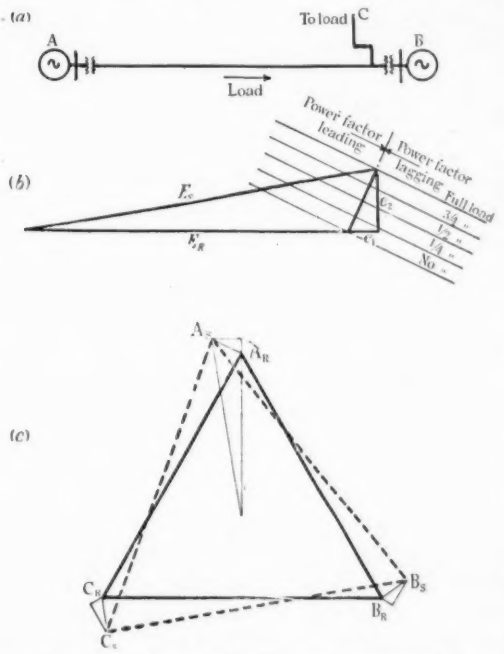


Fig. 16.—Diagram of simple open interconnector.

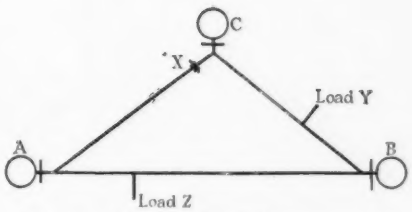


Fig. 17.—Diagram of closed interconnector.

demand. In the closed interconnector these phase angles actually control the flow of power.

Before stating the larger problem let us examine in detail the factors controlling the flow of power in an interconnector. Fig. 16(*a*) represents such an interconnector between two generating stations A and B which are both supplying load to the busbars C. The line has an ohmic resistance of R and reactance X, making an impedance of $R + jX$ ohms. To obtain a voltage of E_R at C to balance the voltage from system B, the sending voltage E_S from system A must be $\{E_R + (e_1 + je_2)\}$. Fig. 16(*b*) shows the vector relationship of these voltages. The locus of E_S, for any given kW load transmitted, passes along a line drawn at right angles to the $(e_1 + je_2)$ vector, and a series of these parallel lines can be drawn for different loadings. The slope of these loci is made up of two components, an in-phase voltage difference which controls the wattless transfer, and a quadrature voltage (which for the small angles considered is proportional to the angular displacement between E_S and E_R) which controls the load. Fig. 16(*c*) is constructed to indicate the 3-phase relationship.

If there are two interconnectors between systems A and B, each having load tapped off, the generators can only take up a mean angular position between the requirements of the two lines and it at once becomes impossible completely to control the transmission conditions without additional apparatus. When three stations are connected as in Fig. 17, the situation becomes more complicated and an excitation adjustment which is normally used for wattless control may completely upset the load balance. Assuming the branch A-C to be opened at X, the three systems are then in series connection and the angular positions between the sets of generators will

adjust themselves to suit the load conditions in the sections A-B and B-C. Transmission power factor and load distribution can be easily controlled. The voltage amplitude and phase positions on either side of the isolator X may be appreciably different. If this isolator is now closed an entirely new set of conditions arises and complete control of load and wattless current is lost. This complete control can be restored by adding a quadrature voltage to the existing in-phase voltage control. Quadrature voltage may be provided conveniently by means of twin-type induction regulators connected as shown in Fig. 18. By means of this double control the voltage triangle in Fig. 16(*c*) may be rotated in space or varied in amplitude to suit any conditions. Only one of these quadrature regulators is needed for each closed loop, and for economy should be placed in the most lightly loaded limb of the closed system.

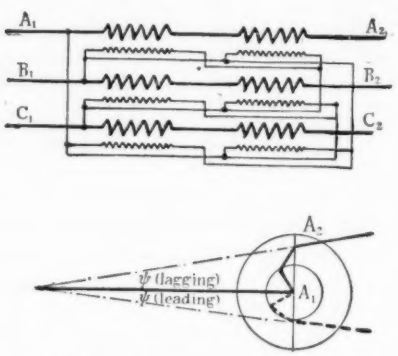


Fig. 18.—Twin regulator for quadrature component.

Special Applications.

The adaptability of the induction regulator has resulted in its application to meet special conditions in many instances. As an example one may take the case of rapidly fluctuating voltages where quick operation to restore the voltage, or swiftly to prevent its departure from normal, is essential. In such cases the movable element of the regulator has been operated by means of an electromagnetically controlled oil servo-motor. By this means constant current has been maintained on special electric welding machines, and satisfactory lighting service taken from feeders operating a traction load. The whole travel of the regulator from minimum to maximum voltage has only occupied $1\frac{1}{4}$ seconds.

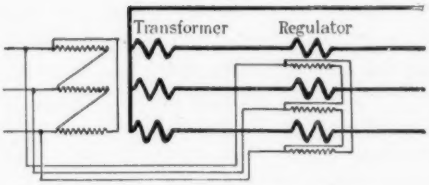


Fig 21.—Three-phase furnace regulator.

Induction regulators have been controlled from thermo-couple pyrometers to maintain constant temperature in an electric furnace, and by watt-meter (or torque) relays to maintain constant kW load.

The small distribution-type regulators, manufactured up to 5 kVA output, for such cases as those indicated in Fig. 14, are made weather-proof and self-contained with their automatic operating gear. They may be mounted on poles as illustrated on page 25 or placed on the roadside in kiosks. The automatic operating gear is a no-contact mechanical device which may be described as a simplified Thury gear. As these small regulators work on almost unity power factor it is customary to provide line-drop compensation by means of reverse series turns on the voltage-control solenoid.

Induction regulators are largely used to obtain smooth voltage control for high-voltage testing equipments, and as phase shifters for other testing requirements. Regulators for this purpose must not distort the voltage wave-form.

Large numbers of regulators have been supplied for electro-chemical and electrolytic processes where smooth control over a wide range of voltage is required. Fig. 21 shows the connections used to obtain the full range (0 to 100 volts, 3,000 amperes) from a 3-phase, 6,600-volt supply. The transformer and regulator each have an output of half the total kVA required, and this results in a highly efficient plant.

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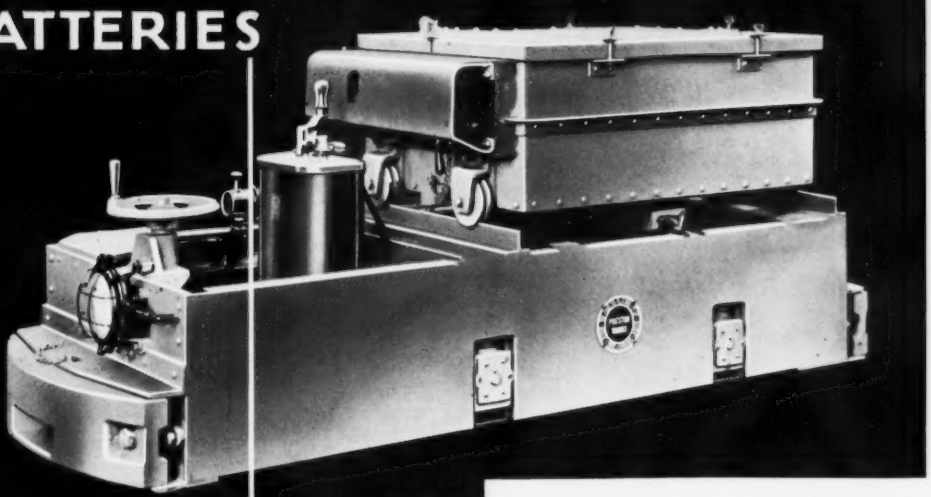

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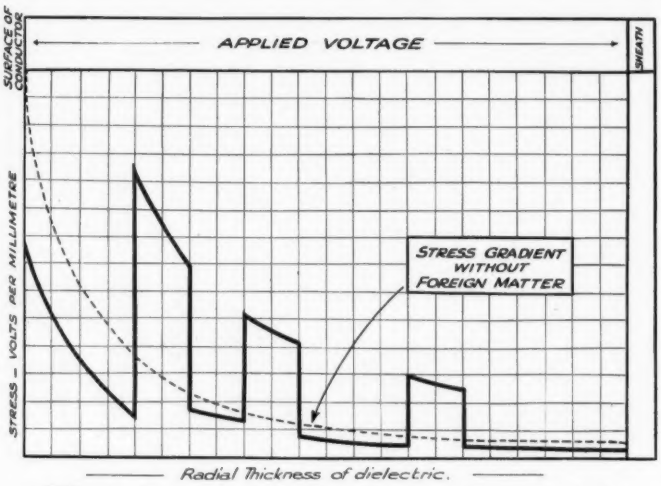
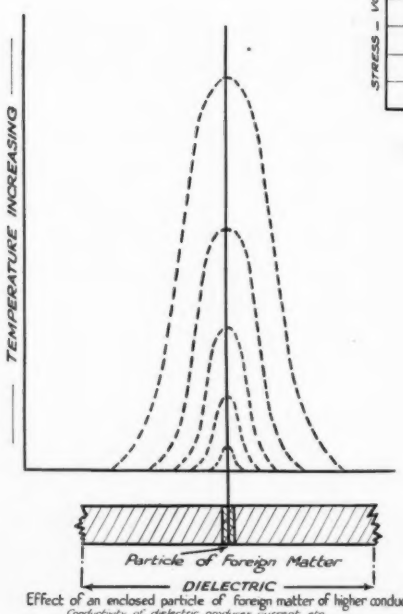


Effect of particles of foreign matter on stress gradient



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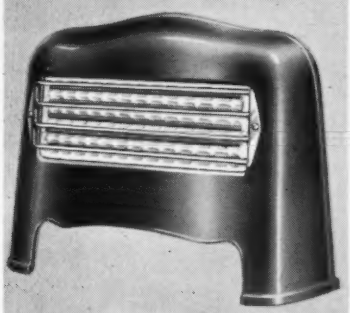

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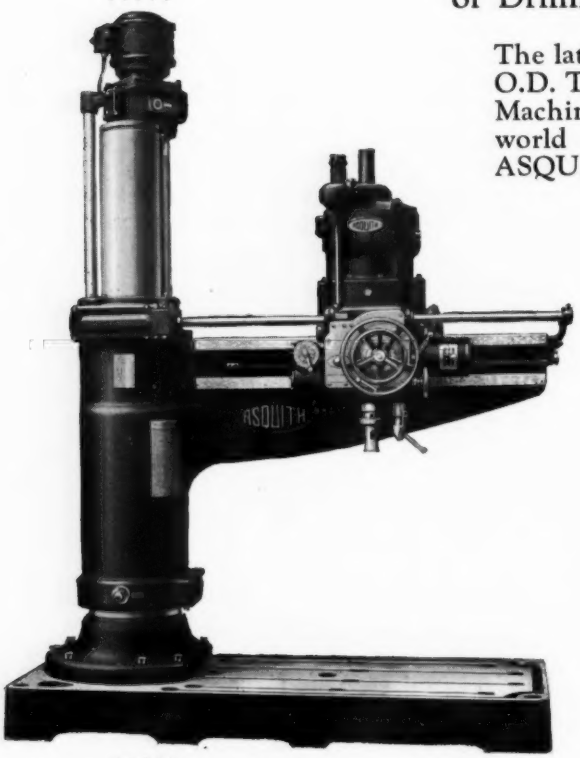

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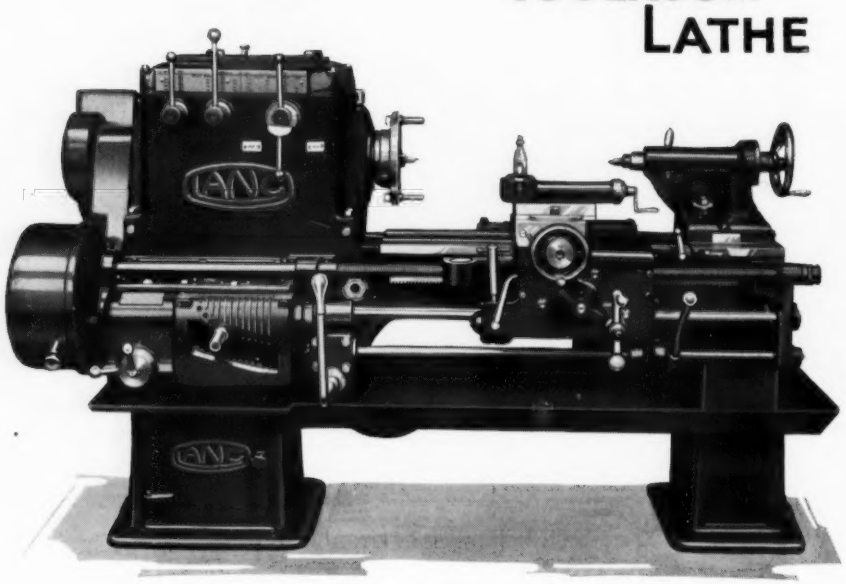

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